Absorption of carbon dioxide during laparoscopy in children measured using a novel mass spectrometric technique

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Background. Carbon dioxide (CO₂) is absorbed during pneumoperitoneum and may cause adverse haemodynamic effects. The aim of this study was to measure the elimination of exogenous CO₂ during laparoscopy in children.

Methods. Ten children [27.6 (56.5) months; mean (SD)] undergoing laparoscopic and nine [24.5 (17.3) months] undergoing open surgery were studied. Breath samples were collected at the line for end-tidal CO₂ and analysed for 13CO₂/12CO₂ ratio expressed as δPDB (difference from standard), by isotope-ratio mass spectrometry. The proportion of absorbed CO₂ was calculated comparing exhaled 13CO₂/12CO₂ before and during CO₂ pneumoperitoneum.

Results. 13CO₂/12CO₂ in medical CO₂ was −32.7 (2.1) δPDB. 13CO₂/12CO₂ in breath of patients undergoing open procedures was −24.3 (2.4) δPDB at the start of operation and did not change during the operation (P > 0.2). 13CO₂/12CO₂ in breath of patients undergoing laparoscopy was −21.5 (5.4) δPDB at the start of insufflation, and decreased during pneumoperitoneum by 2.5 (1.6) δPDB, indicating absorption of exogenous CO₂. The percentage of expired CO₂ absorbed rose to 15.5 (7.7)% after 30 min of pneumoperitoneum and decreased rapidly after desufflation.

Conclusion. After 10 min of laparoscopy 10–20% of expired CO₂ derives from the exogenous CO₂. CO₂ absorption can be measured using a simple mass spectrometric technique.

Keywords: carbon dioxide, absorption; pneumoperitoneum; procedure, mass spectrometry; surgery, laparoscopy

Accepted for publication: April 23, 2006
breath; however, this would be prohibitively expensive at the flow rates of 1–2 litre min\(^{-1}\) during pneumoperitoneum. There are very small differences in \(^{13}\)C/\(^{12}\)C ratio in different naturally occurring carbon sources, and this is reflected in a range of %\(^{13}\)C from 1.0563 to 1.1222. These differences are usually represented as \(\delta\)\(^{13}\)C relative to PDB (Pee Dee Belemnite), the international standard for \(^{13}\)C/\(^{12}\)C. Interestingly, exhaled breath has a rather different \(^{13}\)C/\(^{12}\)C ratio from medical CO\(_2\), reflected by their different \(\delta\)\(^{13}\)C values: breath has \(\delta\) of between –11 and –24 compared with PDB, whereas medical CO\(_2\) has a PDB value of –32 to –34. Hence the absorbed, exhaled medical CO\(_2\) causes the overall \(^{13}\)C/\(^{12}\)C ratio in CO\(_2\) breath to alter, enabling absorption of CO\(_2\) to be measured using a mass spectrometric technique.

**Methods**

Ten children undergoing laparoscopic surgery and nine children undergoing open surgery were enrolled in this prospective non-randomized study. The study was approved by the Research Ethics Committee at the Institute of Child Health and Great Ormond Street Hospital for Children and written consent was obtained for each patient.

**Anaesthesia**

All patients were anaesthetized in a standard manner with either 8% sevoflurane in oxygen or 2–5 mg kg\(^{-1}\) propofol. After induction, atracurium (0.5 mg kg\(^{-1}\)) was administered and the trachea intubated with an oral tracheal tube of age appropriate size with minimal leak present. \(E'_{CO_2}\) was measured on a continuous basis using a positive sampling system (Hewlett Packard, Boeblingen, Germany). All patients were ventilated throughout the procedure with a mixture of air, oxygen and isoflurane to an \(E'_{CO_2}\) level of between 4.5 and 6.0 kPa depending upon the pre-existing pulmonary function.

Paralysis was maintained with boluses of atracurium and intraoperative analgesia achieved with fentanyl up to 5 \(\mu\)g kg\(^{-1}\) in increments plus acetaminophen 30 mg kg\(^{-1}\) per rectum and diclofenac 1 mg kg\(^{-1}\) for those patients over 10 kg. At the end of surgery up to 2 mg kg\(^{-1}\) bupivacaine were infiltrated at the trocars’ insertion sites and the patients were extubated and breathing spontaneously before going to the recovery room.

**Laparoscopy**

A Hasson cannula was inserted under direct vision just above the umbilicus and unheated (room temperature) CO\(_2\) was used to establish a pneumoperitoneum with a pressure of 10–15 mm Hg, according to the surgeon’s preference, and a maximum flow rate of 4 litre min\(^{-1}\). Laparoscopic procedures were performed using standard techniques. Five patients had an open procedure after the end of the laparoscopic procedure.

**Results**

Age at operation was comparable between the two groups, median 8 months (range, 1 month–15 yr) for the laparoscopic group and 24 months (3 months–4.5 yr) for the open group (\(P=0.7\)). Weight at operation was 11.1 (8.6) kg and 11.8 (4.0) kg in the laparoscopic and open groups, respectively (\(P=0.7\)). The surgical procedures performed in each group are listed in Table 1. Core temperature did not show any significant variation and remained within a normal range during the surgical procedure in all patients.
$^{13}$CO$_2$/^{12}$CO$_2$ in medical CO$_2$ was $-32.7$ (2.1) δPDB. $^{13}$CO$_2$/^{12}$CO$_2$ in exhaled breath of patients undergoing open procedures was $-24.3$ (2.4) δPDB at the start of operation and did not change significantly during the operation ($P>0.2$) (Fig. 1A). $^{13}$CO$_2$/^{12}$CO$_2$ progressively decreased during pneumoperitoneum, reducing by 2.5 (1.6) to $-24.1$ (4.1) δPDB ($P=0.0015$ vs baseline by paired t-test with Bonferroni correction) at the end of pneumoperitoneum in each patient [35.0 (19.9) min, range 10–75 min], indicating absorption of exogenous CO$_2$ (Fig. 1B). The percentage of expired CO$_2$ absorbed rose to 16.4 (8.6)% after 30 min of pneumoperitoneum ($P=0.012$), and then decreased rapidly after discontinuing the CO$_2$ insufflation (desufflation) (Fig. 2). As five patients received open procedure after laparoscopy, we were able to obtain additional CO$_2$ samples before extubation, thus establishing that $^{13}$CO$_2$/^{12}$CO$_2$ returns to baseline 30 min after the end of pneumoperitoneum (Figs 1B and 2). After the end of pneumoperitoneum, $^{13}$CO$_2$/^{12}$CO$_2$ returned towards baseline, but required approximately 30 min to return to baseline values (Fig. 1B).

No patients in either group experienced cardiovascular or respiratory compromise during or after surgery and all had an uncomplicated postoperative recovery.

**Discussion**

Laparoscopy introduces new variables into anaesthetic management: effects of elevated intraabdominal pressure, effects of intraperitoneal gas insufflation and alterations caused by differences in patient positioning. As CO$_2$ is highly soluble, it is easily absorbed through the peritoneum. Experimental models in animals have documented CO$_2$ absorption during pneumoperitoneum, causing acidemia, hypercarbia and depressed haemodynamic function.$^{10–12}$ Absorption of CO$_2$ through the peritoneal surface is also documented in adults, resulting in an increase in $E_{CO_2}$.\[^{13–17}\] Although this can lead to a decrease in blood pH,$^{18}$ in otherwise healthy patients undergoing laparoscopic surgery, this CO$_2$ load does not produce a clinically significant respiratory or metabolic challenge$^{19,20}$ and is usually adequately dealt with by an increase in minute ventilation. Several studies in adults have examined the time course of CO$_2$ elimination by indirect calorimetry, and although some authors have suggested that the rate of CO$_2$ elimination reaches a plateau within 15–40 min of pneumoperitoneum,$^{14,16,17,21}$ others have documented increases up to 2 h.$^{22}$ These discrepancies could be related to differences in insufflation pressure, alterations in absorption of CO$_2$ from injured and non-injured peritoneum,$^{15,23}$ or to hypercapnia and CO$_2$ retention in the body. However, in studies using indirect calorimetry$^7$ or respiratory mass spectrometry,$^{15,16}$ to measure total CO$_2$ elimination as the difference between inspired and expired CO$_2$ ($VCO_2$), it is difficult to distinguish between metabolically produced CO$_2$ and CO$_2$
Absorbed through the peritoneum. As substrate utilization and metabolic CO2 production may well change during surgery, the time to achieve plateau VCO2 may vary in different studies depending on metabolic changes, and the estimation of absorbed CO2 is not accurate as it depends on the assumption that metabolic CO2 production is unchanged during the laparoscopic procedure. Few studies have investigated the pathophysiological effects of laparoscopy in children and results have been extrapolated from studies conducted in adults. Similarly to adults, CO2 absorption does not appear to be a problem in patients with normal cardiovascular function and healthy children undergoing short laparoscopic procedures have minimal adverse effects. However, an increase in minute ventilation is usually required to prevent hypercarbia. In previous studies, we have shown, using indirect calorimetry, that children increase VCO2 during laparoscopy and that younger children eliminate relatively more CO2 compared with older children. However, we have also shown that children undergoing laparoscopic procedures are hypermetabolic and would therefore be expected to have an increase in metabolic CO2 production, and an increase in CO2 absorption from the peritoneum. In order to accurately determine the time course of CO2 absorption in children undergoing laparoscopic procedures, we aimed to develop an unambiguous method to quantify the absorption of exogenous CO2, and to use this method to accurately determine the time course of CO2 absorption during laparoscopy in children.

The high precision of isotope-ratio mass spectrometry enabled us to utilize the small differences in natural carbon abundance in different sources (i.e. CO2 metabolically produced from the patient and CO2 used for pneumoperitoneum). Using this technique, we have estimated that 10–20% of CO2 eliminated during laparoscopy in children is derived from absorption through the peritoneum. The variability observed in our study may be related to different insufflation pressures. Minute ventilation was adjusted by the anaesthetist throughout the pneumoperitoneum to maintain E\textsubscript{CO2} between 4 and 6 kPa and none of the patients in the laparoscopic group required desufflation of the pneumoperitoneum and conversion to an open procedure. CO2 absorption reached a plateau after 20–25 min of pneumoperitoneum, a finding comparable with several of the adult studies based on VCO2 measurement. At plateau, 10–20% of exhaled CO2 originated from the pneumoperitoneum, comparable with the 18% estimated by Kazama and colleagues in adults, but somewhat lower than the 30% estimated by Mullet and colleagues. Differences between all these studies may be related to different intraabdominal pressures. This amount of CO2 could potentially cause significant acidosis if not corrected by increased minute ventilation, suggesting that although arterial blood gas analysis is not routinely performed because of its invasive nature, it may be a useful precaution in children with suspected significant arterial CO2–E\textsubscript{CO2} gradients or with pulmonary or cardiovascular compromise. In addition, as absorbed CO2 reached a plateau after about 20 min, any changes in E\textsubscript{CO2} subsequent to this are likely to be attributable to other reasons such as metabolic or haemodynamic alterations, or s.c. CO2 emphysema. As several patients in our series required additional open procedures after the end of pneumoperitoneum, we were able to determine that absorbed CO2 continued to be eliminated for 30 min after desufflation, very similar to the results of Katama and colleagues in adults. Although none of our patients experienced respiratory problems after extubation, the persistent elimination of the absorbed CO2 after desufflation should be taken into account to prevent possible complication in children with pulmonary disease during recovery from anaesthesia.

In conclusion, CO2 absorption from pneumoperitoneum can be measured using a new, simple method which does not require administration of labelled compounds. Using this method, we have demonstrated that in children after 10–20 min of laparoscopy, 10–20% of expired CO2 is derived from the absorption of exogenous CO2, and that exogenous CO2 continues to be eliminated for up to 30 min after desufflation. Further studies using this technique may clarify the exact pathophysiological changes occurring during laparoscopy in children and adults.

Acknowledgements

The authors are grateful to Fondazione Eugenio Litta for a grant to M.P. in support of this work, CHRAT for a summer studentship to C.K., and the Philip Ullman Trust for the isotope-ratio mass spectrometer.

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